EPSC Abstracts
Vol. 11, EPSC2017-623-1, 2017
European Planetary Science Congress 2017

Feasibility and benefits of pulsar planet characterization

J. Nekola Novakova (1,2) and T. Petrasek (1,3)
(1) Charles University, Czech Republic: Faculty of Mathematics and Physics, Department of Geophysics, (2) Charles University, Czech Republic: Faculty of Science, (3) Academy of Sciences, Czech Republic; (julie.novakova@natur.cuni.cz)

Abstract

Planet orbiting neutron stars seem to be rare, but all the more interesting for science due to their origins. Characterizing the composition of pulsar planets could elucidate processes involved in supernova fallback disks, accretion of companion star material, potential survival of planetary cores in the post-MS phase of their stars, and more. However, the small size and unusual spectral distribution of neutron stars (NS) make any spectroscopic measurements very difficult if not impossible in the near future. In this work, we set to estimate the feasibility of spectroscopy of planets orbiting specifically pulsars, and to review other possible methods of characterization of the planets, such as emissions caused by aurorae.

1. Introduction

There are five key ways how a pulsar may acquire planets: i) they could be remnants of planetary cores of objects formed in-situ, ii) they could be objects formed in-situ from the fallback debris after a supernova explosion, iii) they could be objects formed in-situ from a debris disk from a merger of two white dwarfs, which also gave existence to the pulsar, iv) they could be remnants of a stellar companion that lost most of its mass to the pulsar, v) they could be captured objects, most likely from a companion star, less likely rogue planets; however, the scenarios can be distinguished more finely (see [6]). Considering the PSR B1257+12 system [10], Podsiadlowski [6] concluded that a white dwarf (WD) merger is the likeliest scenario. Margalit and Metzger [4] proposed a formation by tidal disruption of a C/O white dwarf companion by the pulsar, specifying a more general companion disruption scenario [11] and providing valuable scenarios of disk evolution for both WD-NS merger disks, but also supernova fallback disks.

The nearly coplanar orbits of the three planets around PSR B1257+12 also suggest formation in-situ. This possibility is further supported by the discovery of a circumstellar disk of the magnetar 4U 0142+61 [9], and a tentative asteroid belt around the millisecond pulsar B1937+21 [7]. PSR B1620-26 b is a circumbinary planet orbiting a pulsar and a white dwarf, and likely formed around the white dwarf precursor, with its system later captured by the pulsar, giving rise to a binary, while the pulsar's original stellar companion was ejected [8]. In a globular cluster with high star density, where this system is present, such an event is more likely than in the galactic disk. Finally, the PSR J1719-1438 system contains most likely a remnant of a disrupted WD companion that narrowly avoided its complete destruction, based on its minimum density [1].

These three known systems represent three of the possible means of origin of pulsar planets. Formation in disks from WD-NS mergers as opposed to supernova fallback disks is also supported by the observed rarity of pulsar planets [2,4]. But we cannot completely discount the option of planetary cores surviving an (asymmetric) supernova explosion, however unlikely it seems. In this scenario, the planets' composition would be heavily altered by the event. Not only would likely only cores of massive and preferably distant planets survive, but the conditions during a supernova explosion, especially the strong neutrino flow, could change the core's chemical make-up as well. However, a detailed model of the compositional changes is out of the scope of this study.

Planets formed from the supernova fallback material – if possible despite its low angular momentum – would also exhibit likely very distinct properties; we could expect metal-rich composition and a variety of short-lived isotopes. Planets arising from WD disruption disks can be expected to have a predominantly carbonaceous composition – essentially to be "diamond planets" [3,4]. On the other hand, planets captured after the explosion would not possess the above-described distinct properties. Finally, planets arising directly from WDs would be recognizable by their extremely high density. Characterization of pulsar planets would be valuable for distinguishing these mechanisms more reliably and constraining the systems' evolution.

2. Characterization feasibility

Due to the small size of neutron stars (approx. 20km diameter), transit probabilities are many magnitudes lower than for planets around MS stars, and unlike them, influenced heavily by the planet's size. Combined with the star's spectrum and known systems' distance, it makes the chance of transmission spectroscopy negligible. The distance and spectral distribution also make potential reflectance spectroscopy extremely unlikely. However, if the planet possesses a magnetic field, cyclotron maser emissions (less likely also optical effects) from its aurorae could be detectable in principle. Pulsar wind charged particles or remnants of supernova fallback/companion disruption disk could provide sufficient environment for this mechanism. Estimating a planet's magnetic field could at least constrain its composition and dynamics. Finally, thermal emissions could be useful for detecting young planets around nearby neutron stars, although their potential for more detailed characterization is rather limited.

3. Conclusions

We conclude that spectroscopic characterization of pulsar planets is highly unlikely to be achieved in the near future, though not entirely impossible, but possible auroral emissions and thermal emissions present more feasible means of at least roughly characterizing planets in pulsar systems. Moreover, they could in theory reveal planets around young pulsars where there is too much timing noise compared to "recycled" millisecond pulsars. While researching pulsar planetary systems could hardly be further from the popular search for "Earth 2.0", it could yield extremely valuable data for planetary science, radio astronomy, astrophysics and other fields, and it could help us answer some fundamental questions about exoplanetary origins and evolutions. For these reasons, we think it worthwhile to pursue this topic.

Acknowledgements

We would like to thank Dr. Paul B. Rimmer for his valuable advice on the topic.

References

[1] Bailes, M., Bates, S. D., Bhalerao, V., Bhat, N. D. R., Burgay, M., Burke-Spolaor, S., ... & Kulkarni, S. R. (2011). Transformation of a star into a planet in a millisecond pulsar binary. Science, 333(6050), 1717-1720.

[2] Kerr, M., Johnston, S., Hobbs, G., & Shannon, R. M. (2015). Limits on planet formation around young pulsars and implications for supernova fallback disks. The Astrophysical Journal Letters, 809(1), L11.

[3] Kuchner, M. J., & Seager, S. (2005). Extrasolar carbon planets. arXiv preprint astro-ph/0504214.

[4] Margalit, B., & Metzger, B. D. (2017). Merger of a white dwarf–neutron star binary to 1029 carat diamonds: origin of the pulsar planets. Monthly Notices of the Royal Astronomical Society, 465(3), 2790-2803.

[5] Martin, R. G., Livio, M., & Palaniswamy, D. (2016). Why are pulsar planets rare?. The Astrophysical Journal, 832(2), 122.

[6] Podsiadlowski, P. (1993). Planet formation scenarios. In Planets around pulsars. ASP conference series (Vol. 36, pp. 149-165).

[7] Shannon, R. M., Cordes, J. M., Metcalfe, T. S., Lazio, T. J. W., Cognard, I., Desvignes, G., ... & Purver, M. B. (2013). An asteroid belt interpretation for the timing variations of the millisecond pulsar B1937+ 21. The Astrophysical Journal, 766(1), 5.

[8] Sigurdsson, S., Richer, H. B., Hansen, B. M., Stairs, I. H., & Thorsett, S. E. (2003). A young white dwarf companion to pulsar B1620-26: evidence for early planet formation. Science, 301(5630), 193-196.

[9] Wang, Z., Chakrabarty, D., & Kaplan, D. L. (2006). A debris disk around an isolated young neutron star. Nature, 440(7085), 772-775.

[10] Wolszczan, A., & Frail, D. A. (1992). A Planetary System Around the Millisecond Pulsar PSR1257 (Plus) 12. Nature, 355(6356), 145.

[11] Yan, Z., Shen, Z. Q., Yuan, J. P., Wang, N., Rottmann, H., & Alef, W. (2013). Very long baseline interferometry astrometry of PSR B1257+ 12, a pulsar with a planetary system. Monthly Notices of the Royal Astronomical Society, 433(1), 162-169.